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METHODS OF CONSTRUCTING CHARTS FOR ADJUSTING TEST RESULTS FOR THE COMPRESSIVE STRENGTH OF PLATES FOR DIFFERENCES IN MATERIAL PROPERTIES

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METHODS OF CONSTRUCTING CHARTS FOR ADJUSTING TEST RESULTS FOR THE COMPRESSIVE STRENGTH OF PLATES FOR DIFFERENCES IN MATERIAL PROPERTIES

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SUMMARY

Methods are presented for constructing charts suitable for adjusting to standard values plate test results for the critical compressive stress and the average stress at maximum load. The methods take into account the difference between the compressive properties of the material used for the tests and those upon which the design is to be based. Illustrative charts are included for extruded 24S-T and 75S-T aluminum alloys.

INTRODUCTION

The results of tests to determine plate compressive strengths, as in the case of columns, cannot be used directly for design purposes, because the compressive properties of the material used for the tests ordinarily differ from the standard values to which the design is to be made. Methods are consequently necessary for adjusting plate test results for differences in compressive properties.

Extensive tests were made recently to evaluate the plate compressive strength of various aircraft structural materials (see summary paper, reference 1) and to show how the compressive strength of plates could be determined from the compressive stress-strain curve for the material. The conclusion was reached that the critical compressive stress for the extruded plate assemblies could be obtained approximately by the use of the secant modulus of elasticity. (See also references 2 and 3.) On the basis of these tests, methods have been devised for adjusting for differences in material properties plate test results for the critical compressive stress and the average compressive stress at maximum load.

For convenience in adjusting plate test results, charts providing adjustment factors are useful for design purposes. This paper therefore presents methods for constructing such charts and includes illustrative charts for extruded 24S-T and 75S-T aluminum alloys.

SYMBOLS

ϵ_{cr}	calculated elastic critical compressive strain
ϵ_{test}	compressive strain taken from compressive stress-strain curve for material tested
σ_{test}	compressive stress corresponding to ϵ_{test}
σ_{std}	compressive stress taken from standard stress-strain curve
$\sigma_{cr_{test}}$	test result for critical compressive stress
$\sigma_{cr_{std}}$	value of $\sigma_{cr_{test}}$ adjusted to standard value
$\bar{\sigma}_{max_{test}}$	test result for average compressive stress at maximum load
$\bar{\sigma}_{max_{std}}$	value of $\bar{\sigma}_{max_{test}}$ adjusted to standard value
σ_{cy}	compressive yield stress (0.2 percent offset)
$\sigma_{cy_{test}}$	compressive yield stress taken from stress-strain curve for material tested (0.2 percent offset)
$\sigma_{cy_{std}}$	compressive yield stress taken from standard stress-strain curve (0.2 percent offset)
K_{cr}	adjustment factor by which $\sigma_{cr_{test}}$ is to be multiplied to obtain $\sigma_{cr_{std}}$
K_{max}	adjustment factor by which $\bar{\sigma}_{max_{test}}$ is to be multiplied to obtain $\bar{\sigma}_{max_{std}}$
C	constant

CHARTS

Charts for adjusting to standard values plate test results for the critical compressive stress and the average stress at maximum load are shown in figures 1 to 3 for extruded 24S-T and 75S-T aluminum alloys. In the following sections, the principles upon which the charts are based are presented and the accuracy and range of applications of the charts are briefly discussed.

<u>Charts for the critical compressive stress</u>.– The results of the tests of the H-, Z-, and C(channel)-section plate assemblies for extruded aluminum and magnesium alloys showed that the basic relationship between the test results for the critical compressive stress $\sigma_{cr_{test}}$ and the calculated elastic critical compressive strain ϵ_{cr} is given approximately by the secant modulus of elasticity taken from the compressive stress-strain curve for the material (see reference 1). Hence for a given value of ϵ_{cr}, the adjustment factor K_{cr} by which $\sigma_{cr_{test}}$ is to be multiplied in order to obtain the standard value $\sigma_{cr_{std}}$ is determined by the ratio of the compressive stress σ_{std} taken from the standard stress-strain curve to the compressive stress σ_{test} taken from the stress-strain curve for the material tested. Thus,

$$\sigma_{cr_{std}} = K_{cr}\sigma_{cr_{test}} \tag{1}$$

where

$$K_{cr} = \frac{\sigma_{std}}{\sigma_{test}}$$

When values of $\sigma_{cr_{test}}$ and ϵ_{cr} and the stress-strain curve for the material tested and that for the standard design are given, values of $\sigma_{cr_{std}}$ may be readily determined from equation (1). Such a procedure, however, is not as convenient as the use of adjustment charts of the nondimensional form given in the ANC-5 bulletin (reference 4) in which only the ratios $\sigma_{cy_{test}}/\sigma_{cy_{std}}$ and $\sigma_{cr_{test}}/\sigma_{cy_{test}}$ are required. Methods for constructing such charts, based upon equation (1), are therefore included and, because of the detail involved, are given in the appendix.

The accuracy of the charts depends first upon whether the buckling stress-strain curve ($\sigma_{cr_{test}}$ plotted against ϵ_{cr}) and the compressive stress-strain curve for the material are affinely related and second upon whether the families of compressive stress-strain curves for a given material are themselves affinely related. For the first condition, the curves are affinely related if one curve can be obtained from another by the transformation $\sigma_{cr_{test}} = C\sigma_{test}$ and $\epsilon_{cr} = C\epsilon_{test}$, where C is a constant and ϵ_{test} is the strain corresponding to σ_{test} from the compressive stress-strain curve for the material tested. Reference 1 showed that the secant-modulus relationship is an approximate one which varies somewhat for different materials and types of plate assemblies. The test results (reference 1) together with unpublished data, however, indicate that an affine relationship between buckling stress-strain curves and compressive stress-strain curves may be expected for a given material and type of plate assembly. Consequently, the value of C is approximately a constant for a given material and type of plate. With regard to the second condition — whether stress–strain curves for a given material are affinely related — observation has shown that such a relationship often actually holds to a good degree of approximation (see reference 5). If affine relationships hold for both conditions, equation (1) is valid and the charts will provide an accurate method for adjusting $\sigma_{cr_{test}}$. Furthermore, if both these conditions are met, the method is general and may be applied to other than extruded materials and H–, Z–, and C–sections.

The marked differences between the charts for extruded 24S–T and 75S–T aluminum alloys (see figs. 1 and 2) emphasize the fact that a chart suitable for one material cannot generally be used for another.

Charts for the average stress at maximum load.— For stresses greater than three-fourths the compressive yield stress σ_{cy}, adjustment charts such as shown in figures 1 and 2 for $\sigma_{cr_{test}}$ can also be used to adjust test results for the average stress at maximum load $\bar{\sigma}_{max_{test}}$, because $\bar{\sigma}_{max_{test}}$ is approximately equal to $\sigma_{cr_{test}}$ in this high-stress region (see reference 1). The same principles and methods for constructing adjustment charts for $\sigma_{cr_{test}}$, consequently, apply to correction charts for $\bar{\sigma}_{max_{test}}$. This method of adjusting $\bar{\sigma}_{max_{test}}$ can be said to be about as general with regard to application to different materials and types of plates as is the method when used to adjust $\sigma_{cr_{test}}$. For stresses below $\frac{3}{4}\sigma_{cy}$, however, this method is no longer valid because values of $\bar{\sigma}_{max_{test}}$ become much greater than $\sigma_{cr_{test}}$ as $\sigma_{cr_{test}}$ is reduced (see reference 1).

A method for approximately adjusting $\bar{\sigma}_{max_{test}}$ over the entire stress range was obtained from an analysis of the data of reference 1 from which the following empirical relationship was found

$$\bar{\sigma}_{max_{std}} = K_{max}\bar{\sigma}_{max_{test}} \tag{2}$$

where

$$K_{max} = \sqrt{\frac{\sigma_{cy_{std}}}{\sigma_{cy_{test}}}}$$

An adjustment chart based upon equation (2) is shown in figure 3. This chart evidently can be applied to H–, Z–, and C–section plate assemblies of extruded 24S–T, 75S–T, and R303–T aluminum alloys. Application of the chart to the test results for extruded ZK60A magnesium alloy in the high-stress region (reference 1), however, did not give satisfactory results, and there is no reason to believe that this method and the relationship upon which it is based are necessarily suitable for materials or types of plate assemblies other than those previously mentioned. As a matter of fact, for stresses greater than $\frac{3}{4}\sigma_{cy}$ where the method for adjusting $\sigma_{cr_{test}}$ also applies to $\bar{\sigma}_{max_{test}}$, K_{max} is a function of $\sigma_{cr_{test}}/\sigma_{cy_{test}}$ as well as $\sigma_{cy_{std}}/\sigma_{cy_{test}}$ (see equation (2)) so that a single adjustment curve (see fig. 3) is not theoretically adequate for accurately adjusting $\bar{\sigma}_{max_{test}}$ in the high-stress region.

VERIFICATION OF CHARTS

In order to provide a verification of the charts for adjusting plate compressive strengths, values of $\sigma_{cr_{test}}$ and $\bar{\sigma}_{max_{test}}$ from reference 1 for H-section plate assemblies are adjusted and compared with similar test data having different values of σ_{cy}. Because the principles of the methods apply equally well to H-, Z-, and C-section plate assemblies, only H-sections are dealt with. Values of σ_{cy} that apply in each case take into account the variation of σ_{cy} over the cross section of the H-sections and were obtained by calculating a weighted average of the values of σ_{cy} for the flange and web based upon the areas of these elements (see reference 1).

The critical compressive stress.- In figure 4, values of $\sigma_{cr_{test}}$ for extruded 24S-T aluminum-alloy H-sections (σ_{cy} = 46.8 ksi, reference 1) were adjusted by means of the chart (fig. 1) for comparison with similar unpublished test results for which σ_{cy} = 40.0 ksi. Good agreement is indicated between adjusted and comparative test results for the extruded 24S-T aluminum-alloy H-sections.

In the absence of test data on two sets of 75S-T aluminum-alloy H-sections of widely different properties, values of $\sigma_{cr_{test}}$ from reference 1 for extruded 75S-T aluminum alloy (σ_{cy} = 78.1 ksi) were adjusted for comparison with similar test results for R303-T aluminum alloy for which σ_{cy} = 71.8 ksi. (See fig. 4.) The less satisfactory agreement in this case is believed to result primarily because the correlation of the test results with the compressive stress-strain curves was not quite the same for the two materials (see reference 1). This lack of agreement again emphasizes the point that the same chart cannot ordinarily be used indiscriminately for different materials if accuracy is desired.

The average stress at maximum load.- In figure 5, values of $\bar{\sigma}_{max_{test}}$ from reference 1 for extruded 75S-T and 24S-T aluminum-alloy H-sections are adjusted by means of the chart (fig. 3) for comparison, respectively, with similar data for extruded R303-T (from reference 1) and 24S-T (unpublished data) aluminum alloys. The fairly good agreement in each case between the adjusted and comparative values of $\bar{\sigma}_{max_{test}}$ for the H-sections indicates that the chart (fig. 3) can apparently be applied to a number of extruded aluminum alloys. This conclusion, however, is in some respects misleading. As previously mentioned, a single curve (fig. 3) cannot be expected to provide an accurate adjustment for $\bar{\sigma}_{max_{test}}$ for stresses greater than $\frac{3}{4}\sigma_{cy}$. The unexpectedly good agreement between comparative results for $\bar{\sigma}_{max_{test}}$ for extruded 75S-T and R303-T aluminum alloys (fig. 5) is not consistent either with this analysis or with the less favorable agreement for the comparative results for $\sigma_{cr_{test}}$ (see fig. 4). Likewise, the relatively poor agreement between comparative results for $\bar{\sigma}_{max_{test}}$ for extruded 24S-T aluminum alloy (fig. 5) does not correspond to the very good agreement for comparative results for $\sigma_{cr_{test}}$ for these materials (see fig. 4). These contrasting results therefore indicate that the use of an adjustment chart for $\bar{\sigma}_{max_{test}}$, employing a single curve and single parameter such as shown in figure 3, does not basically provide an accurate method for adjusting $\bar{\sigma}_{max_{test}}$. The method may suffice, however, as a rough, convenient way for adjusting $\bar{\sigma}_{max_{test}}$ for some materials and types of plate assemblies.

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National Advisory Committee for Aeronautics
Langley Field, Va., February 3, 1948

APPENDIX

CONSTRUCTION OF CHARTS FOR ADJUSTING TEST RESULTS FOR THE CRITICAL COMPRESSIVE STRESS

The charts for adjusting test results for the critical compressive stress $\sigma_{cr_{test}}$ for differences in material properties have the same convenient form as that given in the ANC-5 bulletin (reference 4). Details of the procedure for constructing the charts are outlined as follows:

1. Select a value of $\sigma_{cy_{std}}$ in accordance with the design specifications. In order to illustrate the procedure, $\sigma_{cy_{std}} = 41$ ksi is chosen for extruded 24S-T aluminum alloy ("basis B," table 5-5 of reference 4). The use of the chart, however, is not restricted to this particular value of $\sigma_{cy_{std}}$.

2. Construct a compressive stress-strain curve having the selected value of $\sigma_{cy_{std}}$ from a representative compressive stress-strain curve for the material, assuming the two curves to be affinely related. (See fig. 6.)

3. Construct a family of compressive stress-strain curves by like methods for assumed ratios of $\sigma_{cy_{test}}/\sigma_{cy_{std}}$ of 0.90, 0.95, 1.00, . . . 1.20, and 1.25. (See fig. 6.)

4. The determination of the adjustment factor K_{cr} for given values of $\sigma_{cr_{test}}/\sigma_{cy_{test}}$ and $\sigma_{cy_{test}}/\sigma_{cy_{std}}$ is illustrated by the following example:

(a) Assume that $\dfrac{\sigma_{cy_{test}}}{\sigma_{cy_{std}}} = 1.25$ and $\dfrac{\sigma_{cr_{test}}}{\sigma_{cy_{test}}} = 0.90$. Then,
$\sigma_{cy_{test}} = 1.25 \times 41 = 51.3$ ksi (point A, fig. 6), and
$\sigma_{cr_{test}} = 0.90 \times 51.3 = 46.2$ ksi (point B, fig. 6).

(b) Establish point C (39.7 ksi, fig. 6) on the standard curve directly below point B. The adjustment factor is then (see equation (1))
$K_{cr} = \dfrac{\sigma_{std}}{\sigma_{test}} = \dfrac{39.7}{46.2} = 0.860$ (point D, fig. 1).

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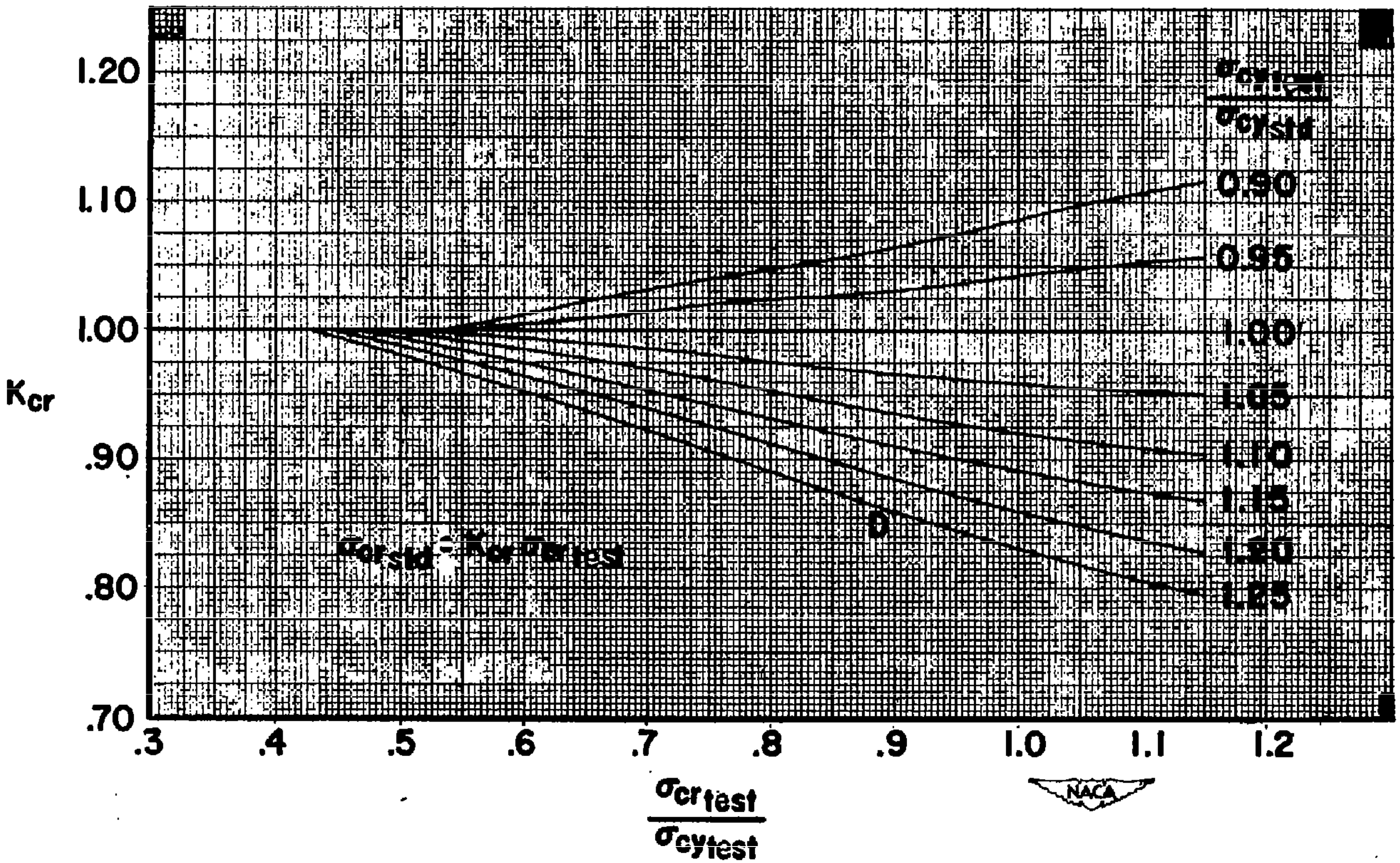

Figure 1.– Factors for adjusting plate test results for the critical compressive stress for extruded 24S-T aluminum alloy.

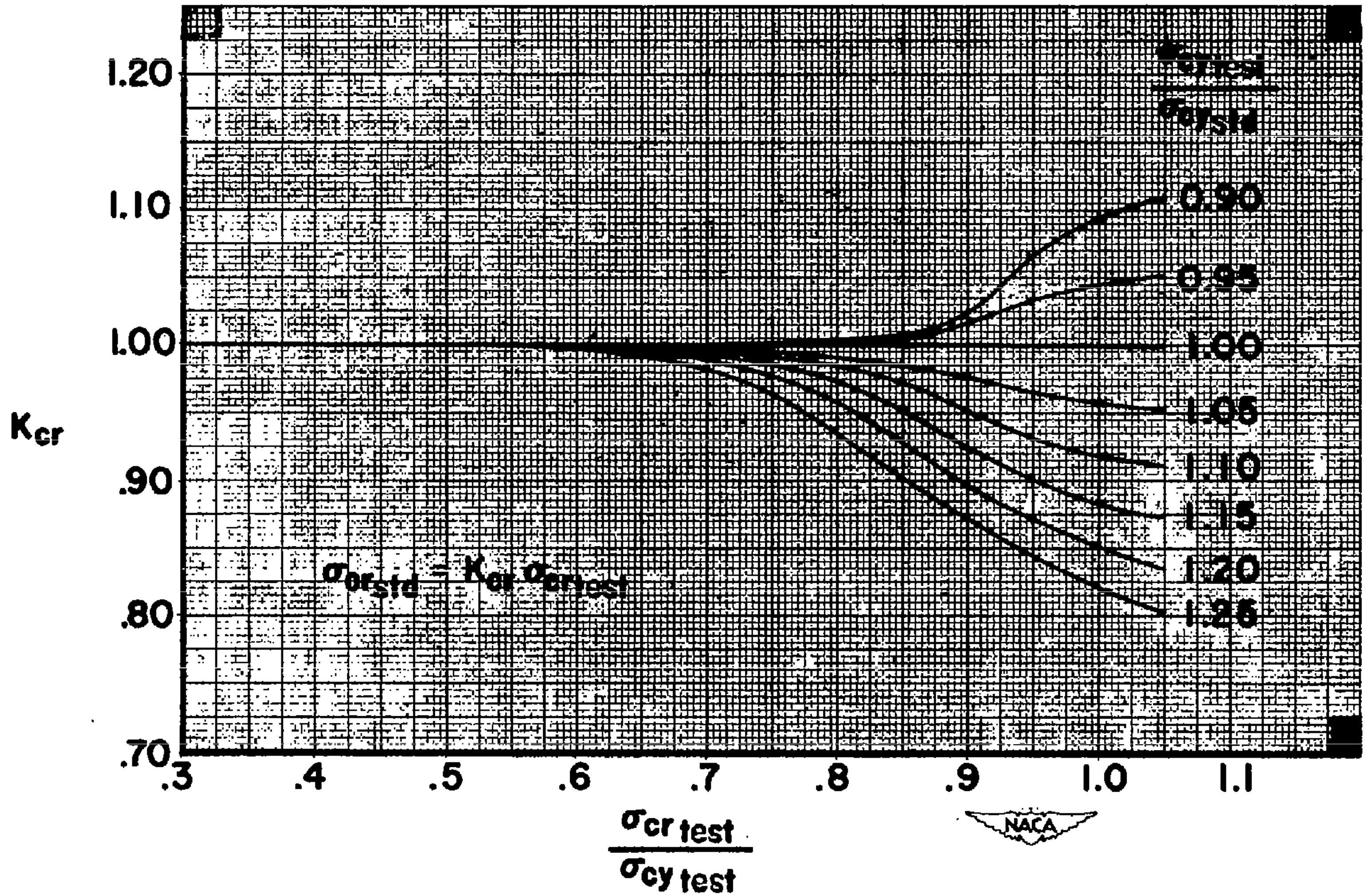

Figure 2.– Factors for adjusting plate test results for the critical compressive stress for extruded 75S-T aluminum alloy.

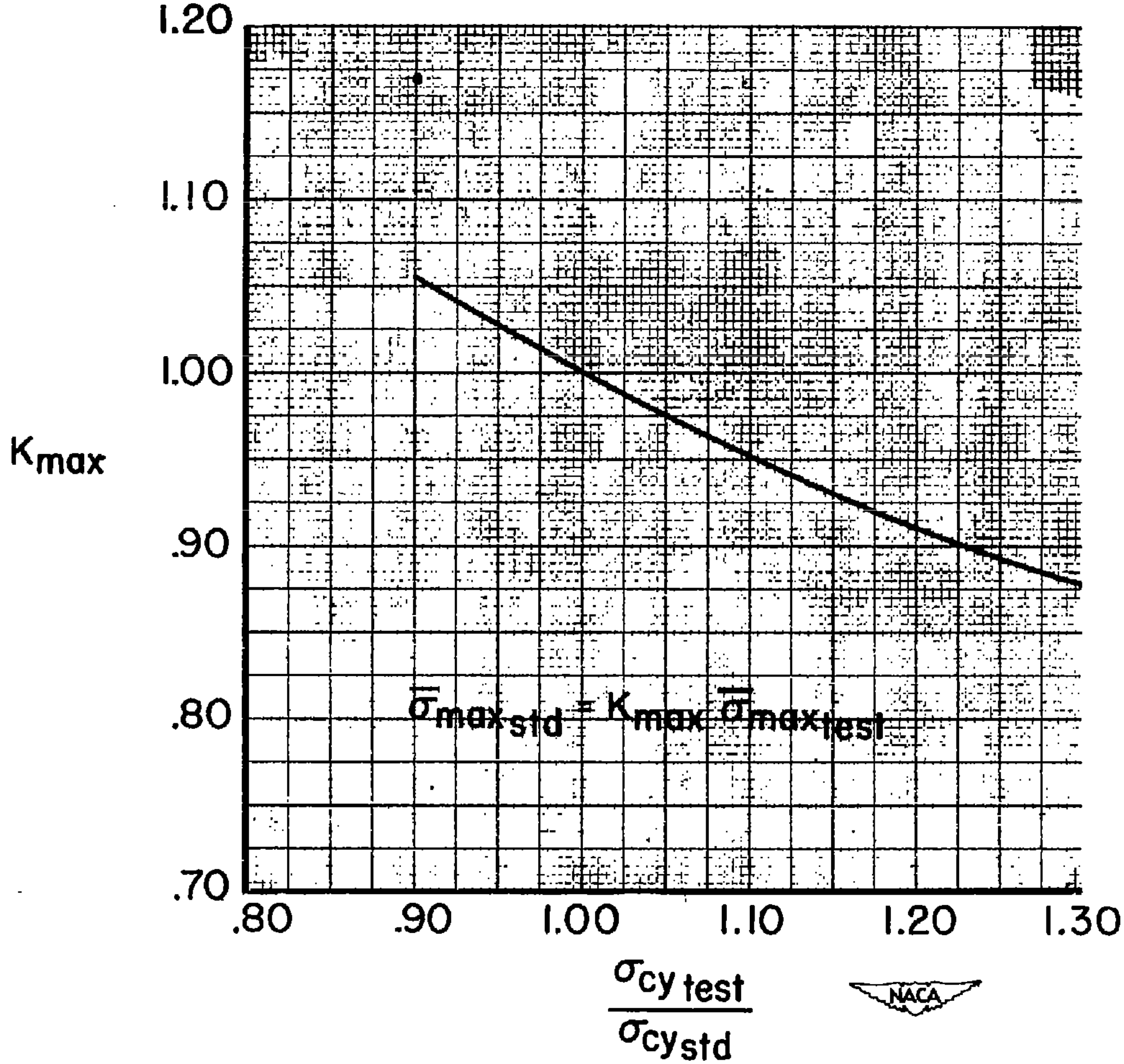

Figure 3.— Factors for adjusting plate test results for the average stress at maximum load for H-, Z-, and C-section plate assemblies of extruded aluminum alloys.

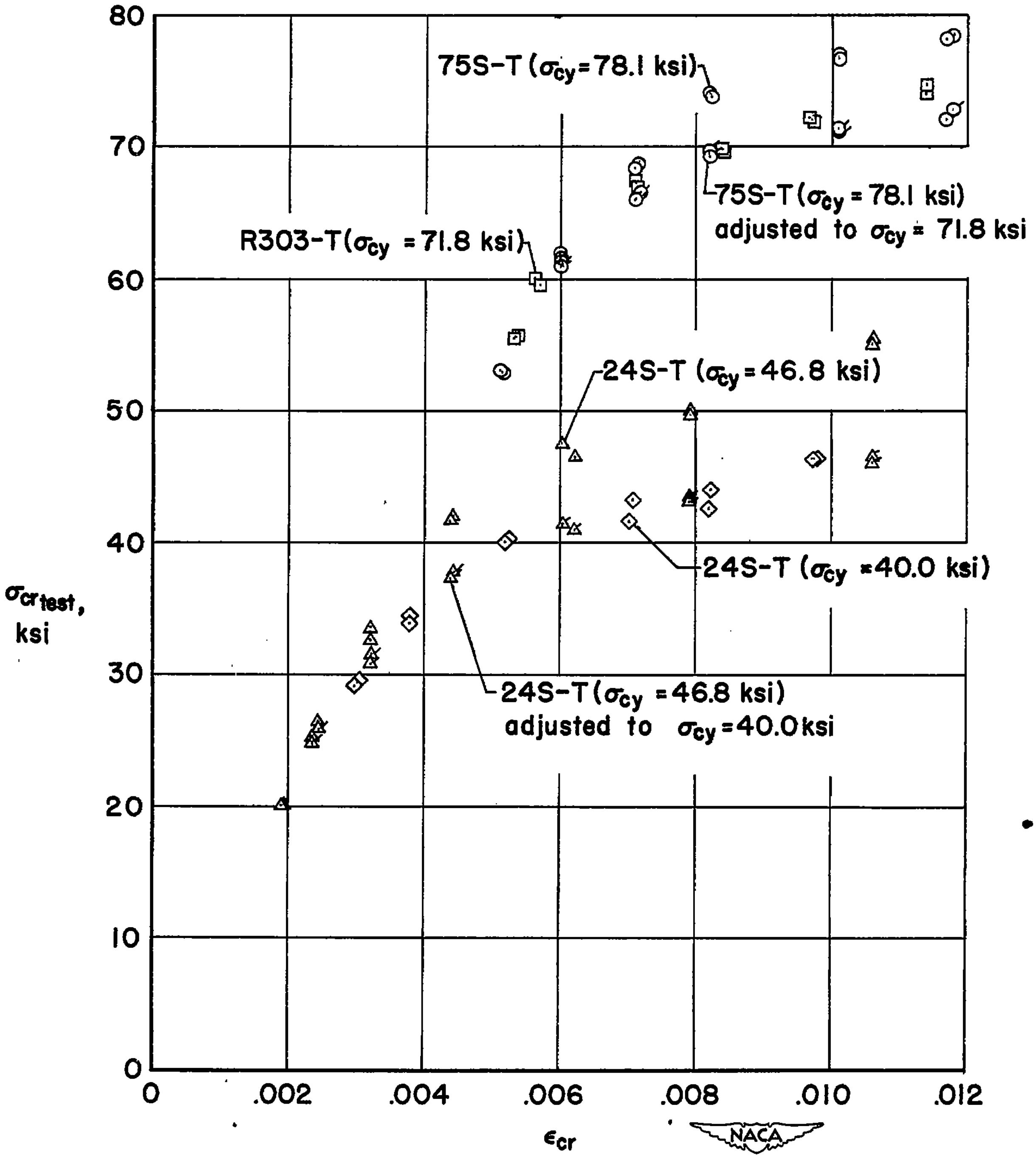

Figure 4.– Comparison of adjusted values of $\sigma_{cr_{test}}$ for extruded 75S-T and 24S-T H-sections with similar data for extruded R303-T and 24S-T.

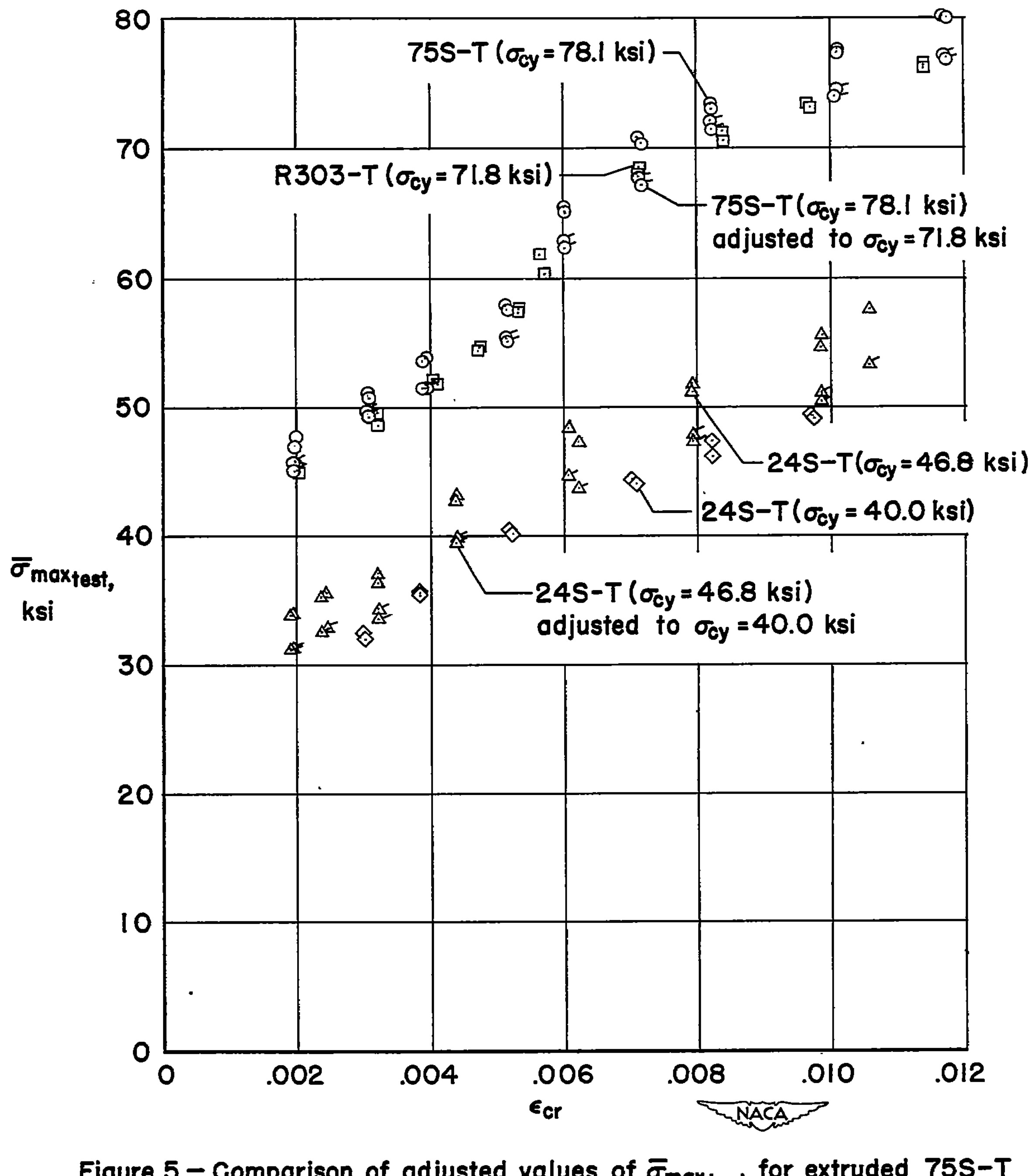

Figure 5.– Comparison of adjusted values of $\bar{\sigma}_{max_{test}}$ for extruded 75S-T and 24S-T H-sections with similar data for extruded R303-T and 24S-T.

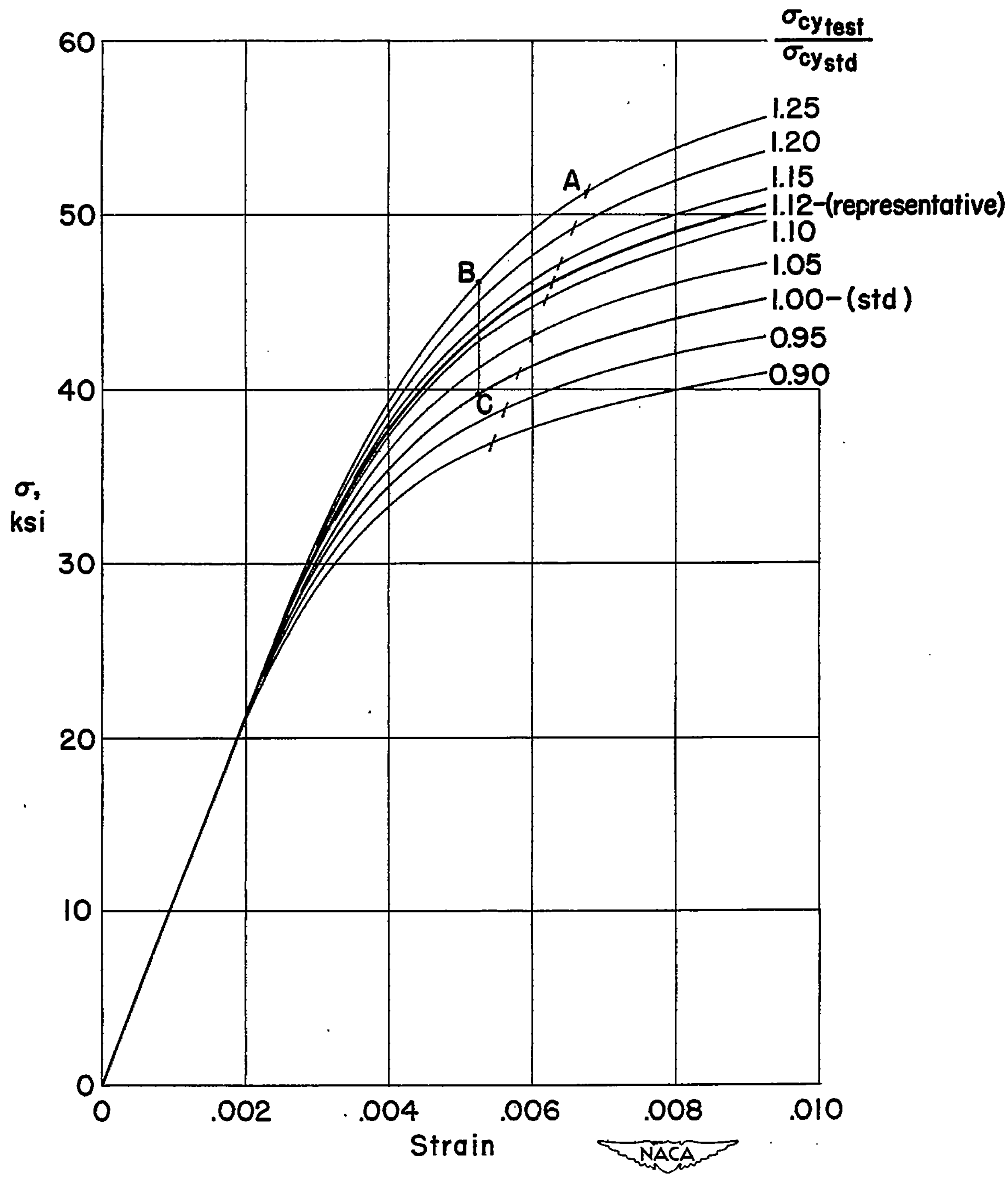

Figure 6.— Compressive stress-strain curves for extruded 24S-T aluminum alloy used in constructing the chart (fig. 1).